AD-A119 862   AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA   F/G 4/2
INVESTIGATIONS OF LARGE SCALE STORM SYSTEMS.(U)
JUN 82   A A BARNES, I D COHEN, D W MCLEOD
UNCLASSIFIED   AFGL-TR-82-0169   NL

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AFGL-TR-82-0169
ENVIRONMENTAL RESEARCH PAPERS, NO. 779

Investigations of Large Scale Storm Systems
Final Report

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8 June 1982

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[illegible] DIVISION PROJECT 2310
AIR FORCE GEOPHYSICS LABORATORY
[illegible]

[illegible] USAF

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-82-0169	2. GOVT ACCESSION NO. AD-A119 862	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INVESTIGATIONS OF LARGE SCALE STORM SYSTEMS FINAL REPORT		5. TYPE OF REPORT & PERIOD COVERED Scientific. Final. 6. PERFORMING ORG. REPORT NUMBER ERP, No 779
7. AUTHOR(s) Arnold A. Barnes, Jr. Ian D. Cohen, Capt., USAF Donald W. McLeod		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (LYC) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2310G501
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (LYC) Hanscom AFB Massachusetts 01731		12. REPORT DATE 8 June 1982 13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cloud physics
Particle size distributions
Crystal habit
Ice content
Water content
Snow growth
Subvisible cirrus
Cirrus
Microphysics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The microphysics of Large Scale Cloud Systems (LSCS) was investigated by in-situ measurements made from two specially instrumented aircraft, a United States Air Force MC-130E and a Learjet 36 Information was obtained on the distribution of liquid and ice water content, particle size distributions, crystal habits, and other meteorological variables. The morphologies of three storms were investigated in detail as the storms crossed the United States.

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Preface

A program of the magnitude of the Large Scale Cloud System involves a great many people who all deserve thanks. It is not practical to list them all as there would be hundreds, but some made major contributions and were close to the core program. The authors wish to recognize the following people and organizations who played major roles in the program:

AFGL Mission Directors

Dr. Arnold A. Barnes, Jr.
Capt. Douglas M. Brooks
Major Donald D. Cameron
Capt Ian D Cohen
Major Leandro V. Delgado
Mr. Morton Glass
Mr. Donald W. McLeod
Lt. Col. Donald J. Varley

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Mr. Vernon G. Plank
Lt. Col. Robert C. Schaller
Mr. Hugh J. Sweeney
Mr. Chankey N. Touart
Ms. Patricia A. Walsh

Computer programs for both real time and post analyses were written by Digital Programming Services Inc. (DPSI). The MC-130E aircraft was operated by the 4950th Test Wing, Aeronautical Systems Division, Wright-Patterson AFB, Ohio. The work of the flight, maintenance, and support crews is appreciated by all who participated in the flights into hazardous weather. In particular, Mr. Drake Daum, as the Test Wing Project Engineer, provided significant support. Aeromet, Inc. operated the Lear 36 aircraft and provided reduced data and analyses. Appreciation is also expressed to Ms. Barbara Main for her assistance in data analysis and Mrs. Carolyn A. Fadden for typing the many versions of the manuscript. Field logistics were coordinated by Mr. Americo S. Cerullo and Mr. John E. Winterbottom.

Several contractors provided especially valuable help. While we cannot list all participating personnel, we can recognize those whose contributions were most significant.

Prof. Richard Passarelli (MIT)
Mr. Michael Francis (DPSI)
Mr. James Lally (DPSI)
Mr. D. Keith Roberts (DPSI)
Mr. John Powers (Systems and Applied Sciences Corp.)

A special thanks to Lt. Col. Robert C. Schalier who reviewed the manuscript and made many helpful and useful suggestions that have been incorporated. This program would not have been possible without the continued support of the then Meteorology Division Director, Dr. Morton L. Barad.

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1. INTRODUCTION

From 1973 through 1977, the Cloud Physics Branch of AFGL (formerly AFCRL) was almost totally committed to the ABRES and Minuteman weather erosion projects at the NASA Wallops Island Missile Range (Plank, 1977 [1]) on the east coast of Virginia and at the Kwajalein Missile Range in the Marshall Islands (Barnes, Nelson, and Metcalf, 1974[2]). As the support for these missile nosecone tests became more routine, AFGL transfered the technology we had developed to contractors and to the ranges so that the Branch could undertake new research ventures in the field of cloud physics and address other Air Force problems.

In support of the reentry vehicle tests at the ranges, we obtained MC-130E Number 640571 (Figure 1) and equipped it with the latest state-of-the-art cloud physics instrumentation (Figure 2). Since the initial support of the weather erosion programs had been a direct transition from some of the basic research we were conducting in cloud physics, and since the MC-130E had the most complete

(Received for publication 7 June 1982)

1. Plank, V.G. (1977) Hydrometeor Data and Analytical-Theoretical Investigations Pertaining to the SAMS Rain Erosion Program of the 1972-73 Season at Wallops Island, Virginia, AFGL-TR-77-0149, AD A051193.
2. Barnes, A.A., Metcalf, J.I., and Nelson, L.D. (1974) Aircraft and Radar Weather Data Analysis for PVM-5, AFCRL-TR-74-0627, AD B004290L.

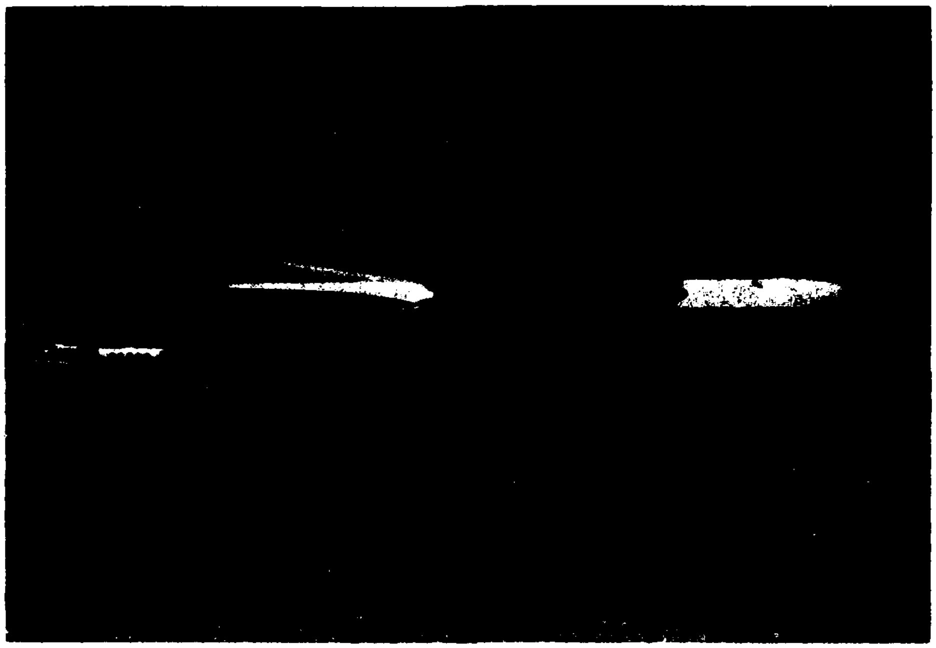
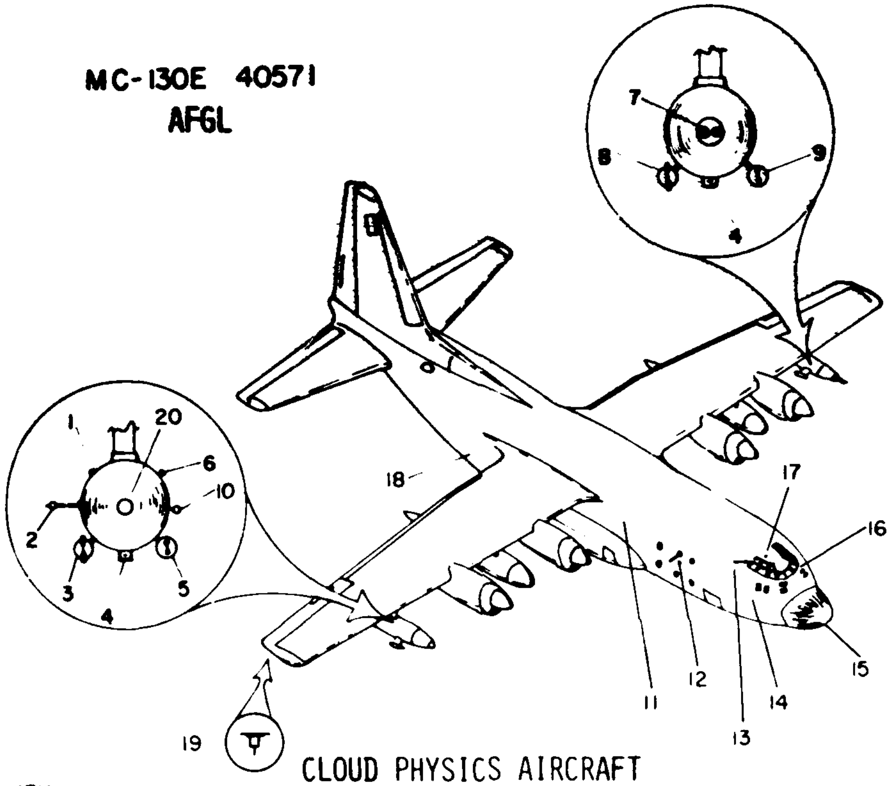


Figure 1. MC-130E Number 640571

and modern state-of-the-art equipment, it seemed only natural and proper to readdress some basic research problems in cloud physics that would make maximum use of our new equipment and experience.

We decided to investigate Large Scale Cloud Systems (LSCS) and to provide information on the distribution of such parameters as liquid water content (LWC), particle size distribution, crystal habit, etc., in these systems. We avoided cloud systems with convective activity because they have characteristic time and length scales that make them difficult to measure with our equipment. Also, convective systems with lightning and turbulence were to be avoided by AF aircraft as directed by AF regulations. Previous investigations had dealt primarily with convective systems because of their high visibility and consequential support by legislative bodies and private hail-suppression groups. Large cloud systems are of interest to the AF because of (1) erosion of the surfaces of hypersonic weapon systems, (2) attenuation of radar returns from targets, (3) visual reconnaissance denial, (4) possible adverse effects on laser weapon and communication systems, and (5) the unknown effects of clouds on the operations of present and future aircraft, and weapons and communications systems. From a scientific point of view a large, slowly evolving weather system is a more tractable problem to handle than the convective type situations where individual cells have a life-time of about 20 min.



KEY

1 DEW POINT HYGROMETER PROBE
2. PMS 1-D AXIAL SCATTER PROBE(2-30μ)
3 PMS 1-D PRECIP. PROBE(300-4500μ)
4. HYDROMETEOR FOIL SAMPLER
5 PMS 1-D CLOUD PROBE (20-300μ)
6. TOTAL AIR TEMPERATURE PROBE
7 EWER PROBE
8. PMS 2-D PRECIP. PROBE(200-6400μ)
9 PMS 2-D CLOUD PROBE (25-800μ)
10 JW CLOUD WATER PROBE
11 PDP-8/E COMPUTER & LINE PRINTER
12 FORMVAR HYDROMETEOR REPLICATOR
13 VISUAL HYDROMETEOR PROBE
14 I N S & DOPPLER RADAR
15 AN/APQ-122 K_a & 5CM WEATHER RADAR
16 16mm NOSE CAMERA
17 PROBE LIGHT
18. TELEMETRY
19. ICING PROBE
20. TWCI

Figure 2. Instrumentation on the MC-130E

The ideal plan would have been to study each storm system using aircraft at a number of levels, with complete weather radar and weather satellite coverage and with an enhanced network of radiosondes and surface observations. We had approached this ideal plan at the missile ranges, but found that we were very much at the mercy of the storms to pass over the radars and surface stations. Other studies, such as CYCLES (Herzegh and Hobbs, 1981[3]) and SESAME (Krietzberg, 1977[4]), encountered the same problem since they were tied to a fixed location. We decided to go to the storm instead and to follow the storm through its life history as it crossed the U.S. In previous studies we had noted some differences in storms at different geographical locations, and we needed more and better observations to support our ideas.

There were some detours from our objectives along the way. The Air Force Office of Scientific Research (AFOSR), which supported this work, was also funding part of the CYCLES program (Herzegh and Hobbs, 1981[3]) and urged us to participate in this program. AFOSR also encouraged us to work with the Advanced Radiation Technology (ART) program and with the Airborne Laser Laboratory (ALL) at the Air Force Weapons Laboratory (AFWL), and, when the AFWL funding was prematurely terminated, completion of the analyses and reports were conducted under the LSCS work unit.

The importance of cirrus clouds as seeding generating cells (Bergeron, 1950[5]), as eroders of hypersonic nosecones (Barnes, Nelson, and Metcalf, 1974[2]), as attenuators of high-power laser beams (Cohen, 1981a[6]), and as spoilers for laminar flow wings (Hall, 1964[7]) lead to research on cirrus clouds.

This work unit also provided the data for the verification and extension of the theory of snow growth that was developed by Professor Richard Passarelli at the Massachusetts Institute of Technology under contract.

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3. Herzegh, P.H., and Hobbs, P.V. (1981) The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones IV: Vertical air motions and microphysical structures of prefrontal surge clouds and cold-frontal clouds, J. Atm. Sci. 38:1771-1784.

4. Kreitzberg, C.W. (1977) SESAME '77 experiments and data availability, Bull. Amer. Meteor. Soc. 58:1299-1301.

5. Bergeron, T. (1950) Uber der mechanssims der ausiebigen nederschlage, Berichte des Deutchen Wetterdienstes 12:225-232.

6. Cohen, I.D. (1981a) Cirrus Particle Distribution Study, Part 8, AFGL-TR-81-0316.

7. Hall, G.R. (1964) On the Mechanics of Transition Produced by Particles Passing Through an Initially Laminar Boundary Layer and the Estimated Effect on the LFC Performance of the X-21 Aircraft, Northrop Aircraft Report.

Modification and improvements of Particle Measuring Systems equipment, development and testing of water content instruments, and a search for a better cirrus particle detector were also undertaken.

The purpose of this report is to summarize the work accomplished under this work unit and to point out areas of future work.

2. AIRCRAFT AND EQUIPMENT

The primary aircraft was the MC-130E that is shown in Figure 1. This aircraft was flown and maintained by the 4950th Test Wing at Wright-Patterson AFB, Ohio. It had been instrumented by General Dynamics to our specifications while it was stationed at Kirtland AFB, Albuquerque, N. Mex. The location of the instrumentation is shown in Figure 2, and the description of the equipment is provided in Table 1. There were continuous updates of the equipment. During the time of the LSCS flights, the downlink, the Total Water Content Instrument (TWCI), and the Rosemont Icing probe were the major additions.

Table 2 is a listing of the flights made by the MC-130E. Some of the flights were made specifically for LSCS studies, others were to collect cirrus data for icing studies or were in support of the ABRES missions. Because of the unpredictable nature of the weather, real-time decisions were made by the on-board Mission Director to change from one mission to another depending on the available weather. The flights in 1976 and 1977 were conducted for ABRES missions, and in retrospect some were found useful for the LSCS studies. Cirrus flights in 1979 were funded by the ART Program of the AFWL, but FY80 funding was not provided by AFWL for reduction of these data. AFOSR suggested that the reports be completed under this work unit because of the importance of cirrus clouds to advanced weapons and surveillance systems.

In May 1981, the equipment was removed from the MC-130E as the aircraft had been reassigned by the AF to another organization for a higher priority mission.

The Learjet 36, number N36TA, had been outfitted according to our specifications to support the ABRES and Minuteman Intercontinental Ballistic Missile (ICBM) reentry nosecone tests at the Kwajalein Missile Range (KMR). Initial installation was done by Meteorology Research Inc. (MRI). Subsequent operations and changes were conducted by Aeromet Corp. In an effort to obtain high-altitude data in the U.S. above the ceiling of the MC-130E, which was about 30,000 feet (10 km), the Lear was utilized to sample up to 45,000 feet (15 km). Table 3 provides a list of these Learjet flights.

Table 1. Specification of Equipment on the MC-130E

Key Number	Equipment	Function	Range of Values	Additional Information
(Ref Fig. 2)				
1	Dew Point Hygrometer	dew/frost points	0° to $+50^{\circ}C$ (dew) 0° to $-75^{\circ}C$ (frost)	Analog output accuracy $\pm 1^{\circ}C$
2	1-D Axial Scattering Spectrometer Probe	particle size and distribution	2-30 μm	All 1-D data are digital and independently recorded
3	1-D Precipitation Probe	particle size and distribution	300-4500 μm	All 1-D data are digital and independently recorded
4	Hydrometeor Foil Sampler	hydrometeor (rain, snow, graupel, hail, etc) measurements	approx 25 μm - 1.95 cm (sampling area 3.81 cm^2)	Mechanical system manual data reduction
5	1-D Cloud Probe	particle size and distribution	20-300 μm	All 1-D data are digital and independently recorded
6	Total Air Temperature Probe	air temperature	-70° to $+350^{\circ}C$	Analog output
7	Ewer Probe	total water and ice	0.05 g/m^3 to approx 3 g/m^3	Inlet area: 10 cm^2 response time: 0.1 sec
8	2-D Precipitation Probe	particle size & distribution	200-6400 μm	All 2-D data are digital and are independently recorded
9	2-D Cloud Probe	particle size & distribution	25-800 μm	All 2-D data are digital and are independently recorded
10	J-W Cloud Water Probe	cloud water content for drops smaller than approx 200 μm	0-3 g/m^3	Analog output
11	PDP-8/E Computer	digital & analog data	N/A	Provides real-time data processing in the aircraft for display and for the downlink (see item 18)

Table 1. Specification of Equipment on the MC-130E (Contd)

Key Number	Equipment	Function	Range of Values	Additional Information
(Ref Fig. 2)				
12	Formvar Hydrometeor Replicator	particle size, distribution, shape & size	50 μm - 1 mm	Manual system uses 16 mm film sample area: 1.65 mm × 6 mm
13	Visual Hydro-meteor Probe (snowstick)	hydrometeor types	50 μm - 1 cm	Used by mission director for qualitative measurements
14	Inertial Navigation System (INS) & Doppler-radar	latitude & longitude	$\pm 90^{o}$ latitude $\pm 180^{o}$ longitude	Part of aircraft equipment: lat & long also in PDP-8/E
15	AN/APQ-122 K_a X-band Radar	quantative weather information	N/A	Used in directing flight operations
16	16-mm Nose Camera	visual recording of clouds & optical phenomena	N/A	Time code is recorded on each frame
17	Probe Light	hydrometeor types	N/A	Illuminates the snowstick at night
18	Telemetry	selectable parameters	output from PDP-8/E	Downlink to provide data to ground stations
19	Ice Detector	icing rate	0.5 mm per cycle	Analog output
20	Total Water Content Indicator (TWCI)	total water content	0.1-3 g/m^3	ASCII/RS232 data output

Additional instrumentation not specifically listed includes:
- 7-Track voice tape recorder.
- Master time code generator.
- 5 Tape recorders (4 digital, 1 analog).
- Remote time displays.
- Indicated air speed, true airspeed, and pressure/altitude sensors.
- Mission Director's panel to set rain/snow type in PDP-8/E.

Table 2. Missions of the MC-130E Relevant to This Work Unit

Flight Number	Date	Project(s)	Sampling Location	Remarks
76-40	15/16 DEC 76	MSV	WAL	MSV support with Lear 36 SASC Case No. [illegible]
77-2	10 JAN 77	MSV	WAL	MSV support with Lear 36 SASC Case No. 4
77-9	23 FEB 77	Compare Probes	FFO TO VPS	Comparison of EWER & PMS probes SASC Case No. [illegible], AFGL-TR-79-0021
77-10	24 FEB 77	MSV	VPS TO WAL TO FFO	MSV support with Lear 36
77-22	20 MAR 77	MSV	WAL	SASC Case No. 6 MSV support with Lear 36
78-4	1 MAR 78	LSCS	ABQ-FMN	
78-5	2 MAR 78	LSCS	LRF-MEM	SASC Case No. [illegible], AFGL-TR-78-0294 LSCS Report, AFGL-TR-80-0002
78-6	3 MAR 78	LSCS	EAST OF DOV	
78-10	23 MAR 78	LSCS	DHT-AMA-Okmulgee, Okla. -Oswego, Kans.	
78-11	24 MAR 78	LSCS	IA-IL	SASC Case No. [illegible], AFGL-TR-79-0007 LSCS Report, AFGL-TR-81-0127
78-12	25 MAR 78	LSCS	OH-W. PA	
78-13	26 MAR 78	LSCS	E. PA	
79-7	27 JAN 79	CIRRUS, ART	EDW-ABQ	Flight included ASSP-FSSP comparison

Table 2. Missions of the MC-130E Relevant to This Work Unit (Contd)

Flight Number	Date	Project(s)	Sampling Location	Remarks
79-8	28 JAN 79	CIRRUS, ART	ABQ-W. TX-ABQ	
79-9	29 JAN 79	CIRRUS, ART	ABQ-PUB-ABQ	LSCS Report, AFGL-TR-80-0324
79-10	2 FEB 79	CIRRUS, ART	ABQ	
79-11	3 FEB 79	CIRRUS, ART	ABQ	
79-12	4 FEB 79	CIRRUS, ART	ABQ	LSCS Report, AFGL-TR-81-0316
79-13	5 FEB 79	CIRRUS, ART	ABQ-FFO	
79-15	15 FEB 79	LSCS, CYCLES	HQM & OLM	Good MIT Spiral, SASC Case No. 17
79-16	17 FEB 79	CYCLES	HQM	SASC Case No. 7
79-17	24 FEB 79	CYCLES	HQM	SASC Case No. 8
79-18	26 FEB 79	CYCLES	HQM	SASC Case No. 9
79-19	27 FEB 79	CYCLES	HQM	
79-20	4 MAR 79	CYCLES	HQM	
79-21	5 MAR 79	CYCLES	HQM	SASC Case No. 10
79-22	6 MAR 79	CYCLES	HQM	
79-23	7 MAR 79	CYCLES	HQM	
79-25	15 MAR 79	CYCLES	HQM	
79-26	17-18 MAR 79	CYCLES	HQM	

Table 2. Missions of the MC-130E Relevant to This Work Unit (Contd)

Flight Number	Date	Project(s)	Sampling Location	Remarks
79-28	29 MAR 79	CYCLES	HQM	
79-29, 30	1 APR 79	LSCS	TCM	Flights included FSSP Test
79-32	5 APR 79	LSCS	TCM-MCC	Flight included FSSP Test
79-33	9 APR 79	LSCS	MCC-DYS	Flight included FSSP Test
79-34	10 APR 79	LSCS	DYS-BLV	SASC Case No. 11. Flights included CIRRUS data
79-35	12 APR 79	LSCS	BLV-BED	
79-40	15 AUG 79	LSCS	EAST OF BOS	SASC Case No. 12
80-4	28 JAN 80	LSCS	FFO	Flight included MIT spiral and icing data
80-5	2 FEB 80	LSCS	FFO-TCM	Subvisible CIRRUS on Ferry Flight
80-6	5 FEB 80	CYCLES	HQM	
80-7	16 FEB 80	LSCS, CYCLES	HQM	MIT spiral
80-8	18 FEB 80	CYCLES	HQM	
80-9	24 FEB 80	LSCS	HQM	MIT spiral and icing
80-10	25 FEB 80	LSCS, CYCLES	HQM	SASC Case No. 16. Good MIT spirals, see Lo and Passarelli, 1981
80-11	26 FEB 80	LSCS, CYCLES	HQM	

Table 2. Missions of the MC-130E Relevant to This Work Unit (Contd)

Flight Number	Date	Project(s)	Sampling Location	Remarks
80-12	27 FEB 80	CYCLES	HQM	
80-13	29 FEB 80	LSCS	HQM	MIT Box Spiral
80-15	7 MAR 80	LSCS	MCC-OFF	SASC Case No. 15
80-16	8 MAR 80	LSCS	OFF-PSM	
80-34	27 OCT 80	LSCS	PIA	Included MIT spiral and icing data
80-36	15 DEC 80	LSCS	PIT & FFO	Included MIT spiral. SASC Case No. 20
80-37	16 DEC 80	LSCS	HYA	Included MIT spiral. SASC Case No. 20
81-1	27 MAR 81	LSCS	FFO	TWCI test
81-2	29 MAR 81	LSCS	FFO	TWCI test
81-3	1 APR 81	LSCS	GRB	MIT spiral
81-6	14 APR 81	LSCS	PWM	Good MIT spiral
81-7	17 APR 81	LSCS	ENE	Good MIT spiral
81-8	18 APR 81	LSCS	ENE	MIT spiral
81-9	23 APR 81	LSCS	ALB	MIT spiral
81-11	29 APR 81	LSCS	PSM & CEF	MIT spiral

Table 3. Cirrus Flights by Learjet 36

Flight Number	Date	Project(s)	Sampling Location	Remarks
1	22 AUG 78	CIRRUS	SNS & TUL	Anvil Cirrus
2	24 AUG 78	CIRRUS	STJ	In-situ, Uncinus, Anvil, Evadus Cirrus and Contrails
3	28 AUG 78	CIRRUS	TUL-OKC-WDG-LAW-ADM-TUL	Uncinus, Anvil, and Evadus Cirrus
4	30 AUG 78	CIRRUS	TUL-ADM-OKC-TUL	In-situ Cirrus
5	8 SEP 78	CIRRUS	TUL-FNL-WDG-HBR	In-situ and Anvil Cirrus
6	19 SEP 78	CIRRUS	GAG	Anvil Cirrus
7	20 SEP 78	CIRRUS	ICT-GAG	Anvil and Evadus Cirrus
8	24 SEP 78	CIRRUS	TUL-MEM	In-situ Cirrus
9	27 SEP 78	CIRRUS	PBG-ALB	Uncinus and Anvil Cirrus
10	29 SEP 78	CIRRUS	TYS	In-situ Cirrus

Figure 3 shows the PMS instruments mounted on the Learjet 36. Table 4 lists the equipment aboard the aircraft. More detailed information can be found in a report by Aeromet (Stickel and Seliga, 1981[8]).

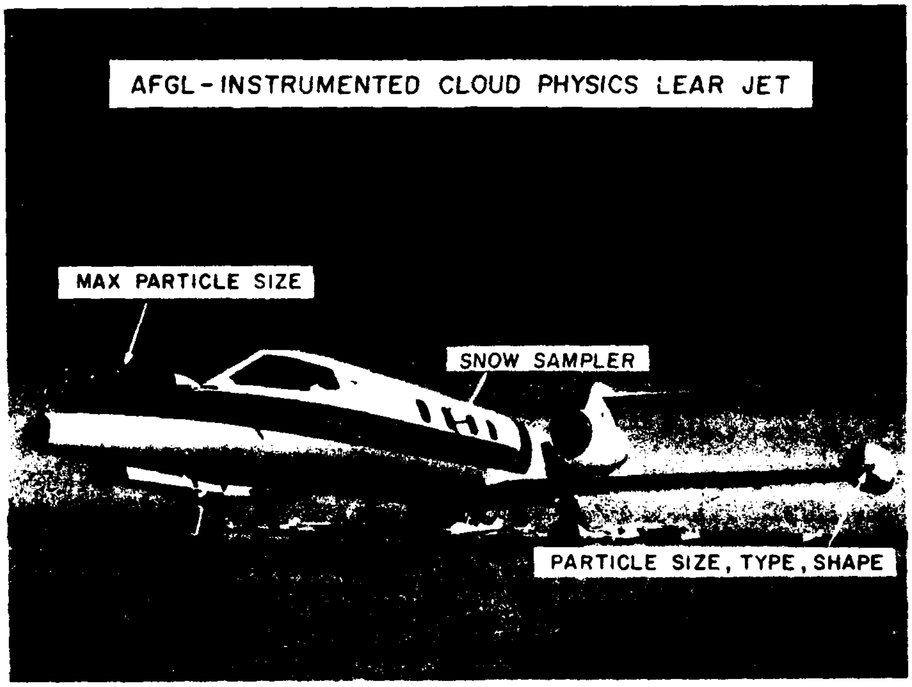

Figure 3. Instrumented Learjet 36 Number N36TA

3. DATA REDUCTION

Both aircraft had on-board computers that were essential for the real-time support of the weather erosion testing at KMR. Data provided in real-time were used in directing the individual flights. In addition, all the data were recorded on magnetic tape and were used in the post-flight analysis.

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8. Stickel, P.G., and Seliga, T.A. (1981) Cloud Liquid Water Content Comparisons in Rain Using Radar Differential Reflectivity Measurements and Aircraft Measurements, 20th Conf. on Radar Met., Boston, 30 Nov-3 Dec 1981, 567-571.

Table 4. Instruments on the Learjet 36

Sensor	Parameter Measured	Range of Values	Additional Information
1-D Axial Scattering Spectromet Probe (PMS)	Particle Size and Distribution	2-30 μm	Digital and Independently Recorded
1-D Cloud Probe (PMS)	Particle Size and Distribution	20-300 μm	Digital and Independently Recorded
1-D Precipitation Probe (PMS)	Particle Size and Distribution	200-3000 μm	Digital and Independently Recorded
2-D Cloud Probe (PMS)	Particle Size, Shape, and Distribution	40-1280 μm	Digital and Independently Recorded
2-D Precipitation Probe (PMS)	Particle Size, Shape, and Distribution	106-5120 μm	Digital and Independently Recorded
Total Air Temperature Probe (Rosemount 102)	Air Temperature	-70 to +50° μm	Analog
Visual Hydrometeor Probe (Snowstick)	Hydrometeor Types and Sizes	50 μm-1 cm	Qualitative Measurements, Lighted for Night Use
16 mm Forward Pointing Camera (Perkin-Elmer J109)	Visual Recording of Clouds and Optical Phenomena	100 ft Reel	Time Lapse. Time Recorded on Each Frame
Altitude/Airspeed Transducer (Rosemount 542K)	Barometric Altitude	0-50,000 ft	
SAT/TAS Computer (IDC)	True Airspeed	0-250 m/s	AC & DC Analog. Also Gives Static Air Temperature

Additional equipment not specifically listed include:

- 2-Track intercom, radio voice, and time tape recorder.
- Telemetry system, downlink, to provide selectable parameters to ground station.
- Computer Automation LSI-2/20 computer for real-time data processing in the aircraft for display and telemetry.
- HF, VHF, and UHF radios for communications and telemetry. WULFSBERG WH18 Flight Fone air to ground radio telephone.
- PMS 1-D data acquisition system and Kennedy tape recorder. 1-D data also goes to the LSI-2/20.

Table 4. Instruments on the Learjet 36 (Contd)

- 2-D data acquisition system and Pertec tape recorder and formatter. Also has a real-time image processor and particle image display.
- IBM-format dual floppy diskette system for program loading and data storage.
- Graphics terminal and CRT display.
- Digital input/output module for interfacing.
- Bendix AVQ-21 weather radar for quantitative information used to direct flight operations.
- Litton LTN-211 Omega navigation system that computes position, headings, and winds.
- Global GNS-500A VLF navigation system that computes position.
- Collins TCN-40 TACAN system that computes distance and relative bearing from station.
- Stancil Hoffman TG2400xB master time code generator.

Writing of the data reduction programs, initial data runs, initial data analysis, and data filtering were done by Digital Programming Services, Inc. (DPSI) for the MC-130E and by MRI and Aeromet for the Learjet. Post-flight output tapes from both aircraft were intentionally made very similar since these tapes were used in the subsequent analyses programs written by DPSI under our direction. Details of the data reduction and analysis programs are in the contractors reports (see list of contractors' reports in Appendix B). Magnetic tapes provided one-sec updates of the data recorded by the PMS one-dimensional (1-D) probes. Meteorological data including temperature and dew point were recorded simultaneously. In addition, on some flights, position, altitude, and wind direction and speed were recorded from the aircraft navigation equipment directly onto our magnetic tapes.

A separate magnetic tape system recorded data from the two-dimensional (2-D) probes. Data from these probes were collected in buffer memories, and when a buffer memory was full, the data were recorded on the magnetic tape. The storage areas were then emptied, and new data were stored there, thus repeating the cycle.

Voice tape recorders provided voice comments from the aircrew and project crew. These tapes provided descriptive comments about the types and quantities of clouds near the airplane. Notes transcribed from these tapes have provided valuable insight into the structure of the cloud systems we have investigated. 16-mm cameras in the cockpits provided additional data. The films from these cameras provided a visual record of each flight. These were supplemented by still photographs taken by the Mission Director, or occasionally by other crew members.

One of the required inputs needed to reduce the PMS data is a definition of the crystal type or habit. This has to be determined for each segment of the flight.

Initially, this information was recorded by the Mission Director during the flight. With the advent of the 2-D PMS probes this can now be determined after the flight if the flights were made in rain or in moderate to large size snow particles. The present method is to manually review the 2-D images, but one of our contractors (ADAPT) is developing a computer pattern recognition method that should automate this function.

To provide full documentation, synoptic analyses of selected cases were provided by Systems and Applied Science Corporation (SASC). These analyses include four published reports which are listed in Appendix B. Several other cases have been documented for us by SASC but have not been issued as reports.

4. INSTRUMENTATION

This section discusses the instrumentation on the MC-130E (S/N 640571) and the Learjet 36 used for atmospheric research. Both aircraft underwent several modifications and incorporated much of the latest equipment available for cloud physics research as well as other state-of-the-art research equipment. These aircraft also allowed for installation of a large variety of sensing equipment without the power, weight, and space restrictions imposed by smaller aircraft.

On the MC-130E an airborne real-time computer capability is provided viz-a-viz a digital computer (DEC PDP-8E), a CRT display console, and a high-speed printer. This high-speed printer and a hard copy unit can provide printed information during and immediately after each flight. The sensor data are provided to the computer in both analog and digital form (as appropriate), and were used to make in-flight test corrections as necessary. A downlink telemetry capability was added to support real-time combined radar, aircraft, and satellite studies.

Post-flight information is provided in a format with all sensor data available at least once a second. These data included the following:

Time (elapsed and zulu)
Liquid Water Content (calculated in grams/meter^3)
Pressure (mbar)
Altitude (m)
Temperature ($^{\circ}$C)
Frost Point ($^{\circ}$C)
Dew Point ($^{\circ}$C)
Indicated & True Airspeed (knots)
Magnetic Heading (degrees)
Relative Humidity (%)

Location (latitude and longitude).*

The LWC calculations were derived from particle count and size data provided by the three 1-D PMS laser spectrometers, measuring particle diameter ranges from 2-6400 μ. Additional data from two 2-D shadowgraph PMS laser spectrometer systems were available to supplement the 1-D data both on a real-time basis from two CRT scopes on the aircraft and on a post-flight basis by dumping the data from the magnetic tapes on a Versatec printer.

Two new state-of-the-art independent systems, the "EWER" (derived from ewer, a wide mouth jar), and "TWCI" (Total Water Content Instrument), which measure total LWC, were undergoing flight test evaluations at the time the aircraft was reassigned. Both the EWER and the TWCI were specifically designed to provide measurements of total ice/water content in the atmosphere. This information is not available from other existing instrumentation, either ground based or airborne. Figure 2 is a schematic diagram of the equipment package on the MC-130E showing the instruments and their approximate locations.

Table 1 is a listing of the major equipment that the aircraft contained with a concise description of the parameter measured, the range covered, and any pertinent additional information.

Figure 3 is a similar schematic of the equipment package on the Learjet 36. Since much of the equipment is comparable to that on the MC-130E, it will not be discussed in detail here. Table 4 lists the Learjet's major equipment in a similar fashion to that listed for the MC-130E.

5. SNOW GROWTH

During the LSCS Flight program, AFGL, along with MIT, looked at the way snow crystals grow. A flight pattern calling for Advecting Spiral Descent (ASD) to be flown with a descent rate of 200 ft/min (approximating that of a snowflake) has been developed and used on twelve flights. This flight pattern increases our understanding of the vertical structure of clouds in a storm. When done in the same storm (on consecutive days), as was done on 7 and 8 March 1980, this pattern can show how a storm's vertical structure changes with time. The technique, developed by Lo and Passarelli (1981)[9] for studying snowflake growth, has

*Note: Many other parameters were available from the Initial Navigation System (INS), but only these were interfaced to the project equipment.

9. Lo, K.K., and Passarelli, R.E. (1981) Height Evolution of Snow Size Distributions, Proceedings, 20th Conf. on Radar Met., Boston, 30 Nov-3 Dec 1981, 397-401.

the greatest chance of success in regions of large-scale winter storms in which vertical air velocities, horizontal gradients, and temperature variations are small.

Their qualitative comparison between data and theory shows that snow growth evolves through at least three stages: deposition, aggregation, and breakup. Deposition initially dominates, but when a sufficient number of large particles has been generated, aggregation becomes the dominant process and produces rapid changes in the size distributions. Breakup eventually limits the production of large aggregations. These airborne measurements suggest that these stages may be detectable by means of vertical incidence Doppler measurements.

6. CYCLES SUPPORT

The MC-130E aircraft was deployed to McChord AFB, Wash., during the late winter and early spring of 1979 and 1980 to participate in the CYCLES (Cyclonic Extratropical Storms) program with the University of Washington. This program explored the structure of storms in the vicinity of the Washington coast in an attempt to determine how various parts of a storm contribute to producing precipitation. The program combined radar and conventional weather observations with airborne data gathered by as many as three aircraft.

Thirteen flights were made in February and March 1979, and seven more were completed in March 1980. Most of these flights sampled storms near the vertically pointing TPQ-11 radar at Grayland, Wash., on the Pacific Coast, southwest of Seattle. Sampling patterns and altitudes varied both with the nature of the storm and the availability of other aircraft. [Airplanes from the University of Washington and the National Center for Atmospheric Research (NCAR) also participated.] In most cases, 5-min data passes were taken at 1000-ft intervals and/or descending spirals were flown near the radar.

Data from most of the flights were provided to the University of Washington. AFGL has reserved the right to use CYCLES data for our research, but due to other requirements, none has been completed.

A paper by Herzegh and Hobbs (1981)[3] covers some recent CYCLES research and gives references to other papers from the CYCLES experiments.

7. STORM FOLLOWING

The use of an airplane makes possible the investigation of the microphysics of a storm as it develops and decays. During the LSCS program, we followed four storms across the country. Our purpose was to provide a look at the changes that

occur in a storm both in time and space. In each case two to four flights were made into the same quadrant of the storm, and a predetermined sampling pattern was flown. Flights were made on consecutive days except when the weather (tornadoes) precluded flying. The exact flight pattern varied from storm to storm but was constant within a given storm. As a general rule, the same project crew, and in most cases the same aircrew (pilot, navigator, etc.) flew all the missions in a given storm. This allowed the same project crew to watch the development and decay as the storm moved across the United States.

7.1 The Storm System of 1-3 March 1978

On 1-3 March 1978, a storm system dominated by an upper level trough moved across the United States. Flights made on those three days provided the data for a study by Varley (1980).[10] Each of the flights collected data in an area east of the upper level trough. This was also usually east of the surface front, although at times there were other frontal boundaries in the area, thus making an exact reference to the position of the surface storm difficult. The sampling area on 1 March was in New Mexico; on 2 March it was in Arkansas; and on 3 March it was over the Atlantic Ocean southeast of New Jersey. Sampling passes were made at various levels, ranging from 29,000 ft (9.0 km) to 5000 ft (1.5 km), generally close to the height of a standard pressure surface. Table 5 shows the number of passes at or near each standard level on each day. Each pass lasted about 20 min, and PMS 1-D and 2-D data, height, temperature, wind, and dew point readings, as well as visual and photographic observations were recorded.

Among the quantities determined from the available data were liquid water content, particle number density, and median volume diameter. These were used to compare the microphysical distributions found at various altitudes. Since the results have already been published (Varley, 1980[10]), only a short summary will be presented here.

Particles in the higher layers tended to have smaller diameters than those found at lower altitudes. The largest particles were found near the melting layer. The largest LWC per unit volume also occurred near the melting layer. The types of particles and calculated LWC were fairly constant at higher levels and varied more from day to day at lower levels.

The storm itself had moved from a continental system to an oceanic system. On 1 March, it had little precipitation associated with it, while on 3 March, it had a large shield of rain and snow. This was mainly the result of an influx of low level moisture; the upper level structure remained much the same.

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10. Varley, D.J. (1980) Microphysical Properties of a Large Scale Cloud System 1-3 March 1978, AFGL-TR-80-0002, AD A083140.

Table 5. **Passes at or Near Each Standard Pressure Surface 1-3 March 1978**

Pressure Surface and Approximate Height	Passes on 1 March	Passes on 2 March	Passes on 3 March
300 mb (9.0 km)	1	0	0
400 mb (7.3 km)	1	1	2
500 mb (5.5 km)	1	0	2
700 mb (3.0 km)	1	1	2
850 mb (1.5 km)	0	1	0

7.2 The Storm System of 23-27 March 1978

During the same month as the previous storm, another storm was followed from its beginning as a low pressure cell on a stationary front in Oklahoma to its dissipation over the Gulf Stream off the east coast of the United States. Cohen (1981b)[11] reported on the morphology of this system. It is also the subject of study by Dyer and Cohen (1982)[12]. The large cloud shield permitted flights into the northeast quadrant of the storm on 23, 24, 25, and 26 March. On each flight, a sampling pass of at least 20-min duration was completed at 850 mbar (1.5 km), 700 mbar (3.0 km), 500 mbar (5.5 km), and 400 mbar (7.3 km). This consistent pattern provided cross sections of the storm both in time and space. The data taken included the same types of measurements as in the 1-3 March case.

As in the 1-3 March storm, the upper levels generally contained smaller particles. In addition, the distributions at higher levels were the most consistent, having the most uniform sizes of any particle distributions. Again, the highest LWC values were found near the melting layer. The largest number of particles per unit volume also were found near the melting layer, which was most frequently at or near 700 mbar.

On the first day, the system contained some convective activity. This resulted in a more uniform distribution of particles with respect to altitude. On the second and third days there was less convective activity, and particle size and

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11. Cohen, I.D. (1981b) Development of a Large Scale Cloud System, 23-27 March 1978, AFGL-TR-81-0127, AD A106417.

12. Dyer, R.M., and Cohen, I.D. (1982) Changes in the Nature of Fluctuations of Temperature and Liquid Water Content During the Lifetime of a Large Scale Storm, AFGL-TR-82-0147, (in publication).

density varied more with altitude. On the fourth day there was a resurgence of convective activity associated with the system, but none was observed near the sampling area. As a result, while a cursory examination of the data showed more in common with the third day, a harmonic analysis of the data showed more in common with the first. Although the system may have appeared to be regaining strength, it soon moved over to the ocean and dissipated.

7.3 The Storm System of 10-12 April 1979

On 10-12 April 1979, a storm that contained primarily convective clouds was followed from Nebraska to New York. Unfortunately, the lack of large thick continuous cloud shields prevented us from obtaining data passes similar to those completed for the 1978 storms. In addition, terminal weather at Scott AFB, Ill. (severe thunderstorms and tornado warnings) on 11 April precluded a flight on that day. Thus, a disorganized variety of passes on 10 and 12 April were all that we could gather. For this reason, this system has not been the subject of a report.

Five passes were completed on 10 April, and three were flown on 12 April. Passes on the earlier day ranged in altitude from 1.8 km (6000 ft) to 7.4 km (24,300 ft). The first four passes were flown at approximately the 400-, 500-, 700-, and 800-mbar surfaces. The last pass occurred during the aircraft's climb to its crusing altitude. The sampling area was in central Nebraska. The passes on 12 April were taken during a flight from Scott AFB, Ill. to Hanscom AFB, Mass. Unlike other flights of this type, the passes covered consecutive portions of the flight track rather than all being in the same area. We thus sampled a long horizontal corridor rather than a vertical cross section of the atmosphere.

The flight on 10 April was in a storm that had considerable convective activity. As a result, the high-level clouds contained a larger variety of particles than those seen in flights in storms with less convective activity. Much of the cirrus may have originated as part of cumulonimbus anvils. There was little cloud at middle levels, while the stratocumulus clouds found at 5000 ft (1.9 km) consisted mainly of small water droplets. There was some buildup in the lower cloud levels and some evidence that these areas were "seeded" by particles falling from the cirrus clouds.

On 12 April, sampling was confined to 15,000 ft (4.6 km) and higher. The cirrus at higher levels consisted of small, uniformly-sized particles, similar to those seen in similar positions in relation to other storms. The last pass, during which the aircraft descended from 17,500 ft (5.3 km) to 15,000 ft (4.6 km) ended in the bottom of a level of middle cloud ahead of the warm front. This portion of the cloud contained unusually large snow particles for that altitude. This was

probably the result of warm air over-running the colder air, thus "climbing" the warm front. Particles from lower levels were lifted with the air and thus grew to diameters of 4000 μm or larger.

The lack of a consistent data-gathering pattern makes analysis of this case difficult. It can, however, provide supplemental data to compare to other cases.

7.4. The Storm System of 7-8 March 1980

Two flights were made into a fast moving storm on 7-8 March 1980. Due to the nature of the storm, time did not permit a full-scale sampling pattern. Spiral descents were performed in Kansas and Maine. Data from this case have been used in studies on snow growth and aircraft icing.

8. CIRRUS STUDIES

A study of tenuous clouds was started in 1978. At the request of the AFWL, the MC-130E sampled thin cirriform clouds and also investigated the marine boundary layer (the first 1000 ft above the surface of the ocean). The study of cirrus clouds is also important to the study of large-scale cloud systems; therefore, this study was continued under the LSCS program after the AFWL funding for the cirrus study was terminated.

Of the ten reports published as part of the study on tenuous clouds, three [Cohen and Barnes (1980),[13] Varley, Cohen, and Barnes (1980)[14] and Cohen (1981a)[6]] deal primarily with cirrus that was associated with a large-scale cloud system. These reports were parts 6, 7, and 8, respectively, of the AFGL Cirrus study.

8.1 4-5 April 1978

The flights on 4 and 5 April measured cirrus associated with a new frontal system that moved through the southwestern United States. The flights are described by Cohen and Barnes (1980);[13] data were collected in northwestern New Mexico before (4 Apr) and after (5 Apr) the passage of a cold front.

Cirrus ahead of the front varied from thin to moderately opaque. Particles were usually 700 μm or less in length. After passage of the front, the only visible cloud remaining within the aircraft's altitude limits were some thin cirrus. This cirrus was probably fallout from a higher cirrus layer.

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13. Cohen, I.D., and Barnes, A.A. (1980) Cirrus Particle Distribution Study, Part 6, AFGL-TR-80-0261, AD A096772.

14. Varley, D.J., Cohen, I.D., and Barnes, A.A. (1980) Cirrus Particle Distribution Study, Part 7, AFGL-TR-80-0324, AD A100269.

In addition to the visible cirrus, there were two types of subvisible cirrus (particles in apparently clear air). One type (Barnes, 1980a)[15] was an almost continuous background of particles generally less than 6 μm in size. This type was especially common ahead of the front. A second type consisted of large particles (600-1200 μm) that were not sufficiently dense to produce visible cloud. A fairly extensive area of this type of cirrus was encountered on the 5 April flight.

8.2 28-29 January 1979

Two flights in the cirrus shield associated with a fairly intense storm in eastern New Mexico were among those examined by Varley, Cohen, and Barnes (1980).[14] The flight of 28 January occurred just as the low pressure center was beginning to intensify. At this time moist southeast winds at low levels and strong southwesterly winds aloft enabled the system to intensify. The resultant cirrus varied from thin to dense and contained a large variety of particle sizes and types. By 29 January, the storm had intensified considerably and caused a widespread area of rain and snow. The cirrus was thicker, at a lower altitude, and again displayed many different particle sizes and shapes. The strong vertical currents in the storm no doubt helped to create larger cirrus particles.

The cirrus in this system contained larger particles than that associated with the weaker case observed on 4-5 April 1978. In the 28-29 January storm particles as large as 1100 μm were common, and some as large as 1300 μm were found. This is in contrast to the 700-μm maximum size that was typical of the cirrus observed on 4-5 April.

8.3 2-4 February 1979

Flights made on 2, 3, and 4 February 1979 sampled cirrus in New Mexico and western Texas. During this period, no strong surface features were present, and as a result, the cirrus was usually thinner, with fewer and smaller particles occurring in the clouds. Subvisible cirrus of both types also was found. These flights are described in parts 7 and 8 of the cirrus study.

8.4 5 February 1979

On 5 February, the MC-130E flew from Kirtland AFB, N. Mex. to Wright-Patterson AFB, Ohio. During its flight it passed the northern edge of the cloud

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15. Barnes, A.A. (1980a) Ice Particles in Clear Air, Preprints, 8th International Conference on Cloud Physics, Clermont-Ferrand, 15-19 July 1980, 189-190; AFGL-TR-81-0009, AD A094444.

shield produced by a storm in the Gulf of Mexico. A report on this flight was included in Part 8 of the cirrus study.

The 5 February flight sampled several types of cirrus; two samples were taken from the one-hour period during which the aircraft was in the aforementioned shield. This cirrus consisted almost entirely of smaller particles, the maximum size being about 400 μm. Thus, although frontal in origin, this cirrus was beginning to look more like non-frontal, non-storm-related cirrus. In all probability, the larger particles had fallen out of the cloud as it moved farther from the storm system due to the stronger upper level winds.

8.5 Instruments to Detect Small Cirrus Particles

It was recognized that there was a need to make quantified measurements of the smaller cirrus particles, those less than about 50 μm in diameter, and that the available in-situ, airborne instruments seemed inadequate (Barnes, 1978).[16] Hallett (1980)[17] made a detailed critical review of available instrumentation from the point of view of representative data acquisition in a realistic time frame. In particular, he concentrated on techniques for measuring mass and size distribution. He concluded that two untried techniques utilizing particle accretion and evaporation showed some promise for measuring mass distribution.

9. SUBVISIBLE CIRRUS

Observations made during the time we were studying LSCS led us to believe that cirrus clouds invisible to an observer could exist; in many instances, cirrus clouds would appear at sunrise or sunset but be invisible during other times of the day. In other cases, a thin, hazy cloud could be seen from an airplane, while ground-based observers were reporting clear skies. In yet other instances, our PMS equipment reported particles while the airplane was flying in apparently clear air. Barnes (1980a)[15] looked at these situations, especially the latter, and described two types of cirrus clouds that were invisible. He called them subvisible cirrus.

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16. Barnes, A.A. (1978) New Cloud Physics Instrumentation Requirements, Preprints, 4th Symposium on Meteorological Observations and Instrumentation, Denver, 10-14 April 1978. Published by the Amer. Meteorological Soc., Boston, 264-268, AFGL-TR-78-0093, AD A053235.

17. Hallet, J. (1980) Characteristics of Atmospheric Ice Particles: A Survey of Techniques, AFGL-TR-80-0308, AD A093927.

9.1 Background Cirrus

In our cirrus research flights, we usually observed at least a small number of particles in the 1-10 μm size range. At first we thought these were merely "noise" but, on closer examination, realized that they were by no means constant. At times, no particles would be recorded in this size range; at others, they would be quite common, even though in each instance the sky would appear to be clear. Figure 4 [from Cohen and Barnes (1980)[13]] shows how this background can vary under apparently clear conditions. Thus the "background" actually resembles a cirrus cloud that is too thin to be seen by the eye. The line called "cloud conditions" on Figure 4 indicates what the observer saw. Solid black lines represent times when the aircraft was in cloud; shaded lines represent times that the airplane was near clouds but did not appear to actually be in them. As a rule, it takes a certain density of particles between 20 and 200 μm to make the cirrus visible. Usually, this density is about 10^4 particles per m^3.

9.2 Isolated Particles

The second type of subvisible cirrus consists of large, isolated ice crystals. Cohen and Barnes (1980)[13] observed particles as large as 2300 μm in a case in New Mexico. These particles may form in clear air, but in most cases they fall from higher clouds. They may fall into warmer air at lower levels and melt there. In very cold climates, they may fall to the ground, resulting in a phenomena sometimes called "Diamond Dust" snowfall (Barnes, 1980b[18]).

10. DISCUSSION

10.1 Extratropical Cyclones, Progress and Research Needs

The report on the Workshop on Extratropical Cyclones (Hobbs and Reed, 1979[19]) held in Seattle, Washington, 10-12 September 1979 summarized the research needed to fill the gaps that presently exist in our knowledge of extratropical cyclones. Since cyclones dominate mid-latitude weather, more accurate forecasts would provide important benefits such as greater agricultural production, better management of water resources, flood control, and disaster avoidance.

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18. Barnes, A.A. (1980b) Observations of ice particles in clear air, Journal de Recherches Atmospherique 14(No. 3-4):311-315, AFGL-TR-81-0347, AD A108914.

19. Hobbs, P.V., and Reed, R.J. (1979) Extratropical Cyclones, Progress and Research Needs, Workshop held in Seattle, Washington, 10-12 September 1979, 45 pp.

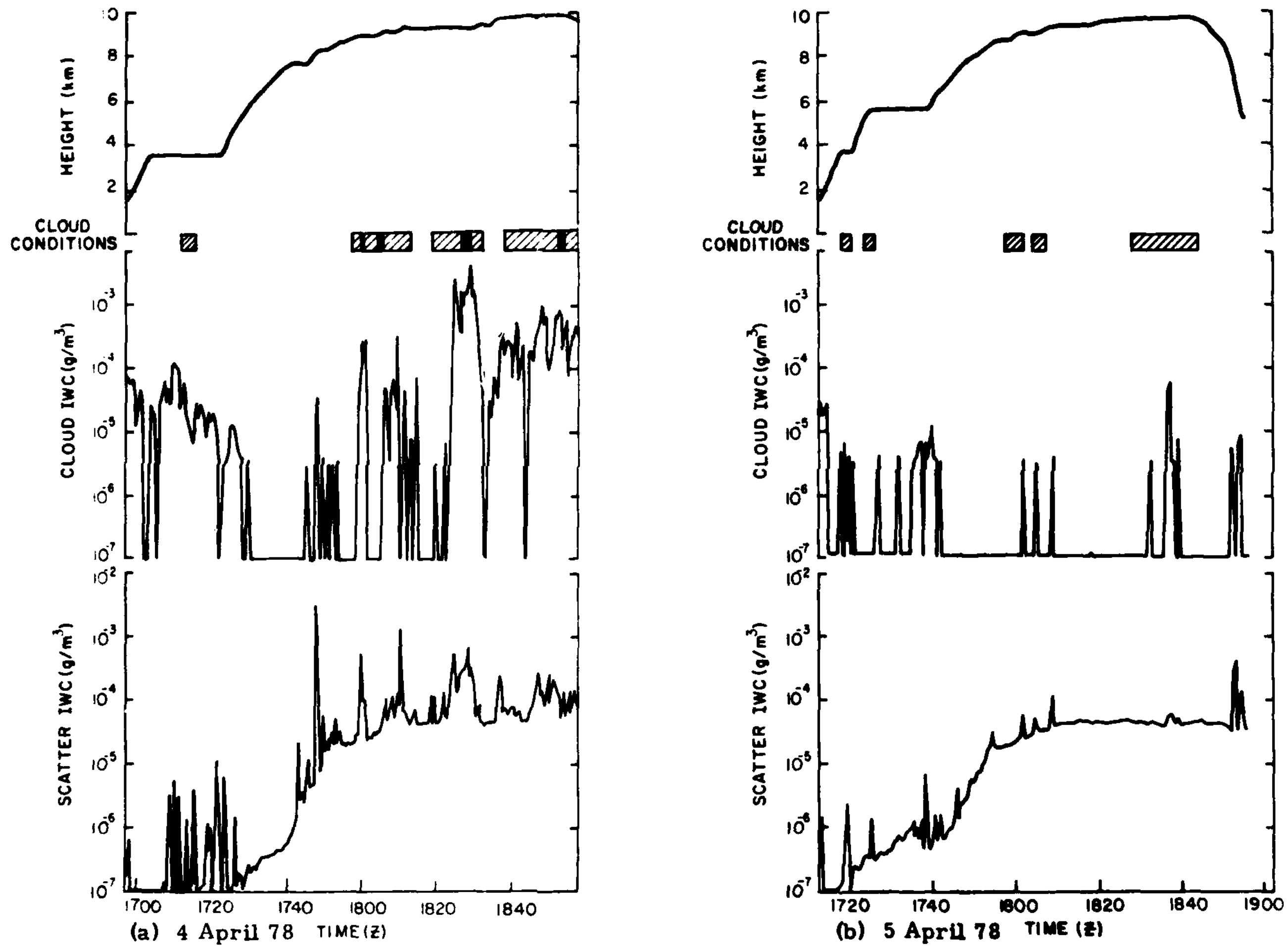

Figure 4. Ice Water Content and Cloud Cover vs Time for Flights of 4 and 5 Apr 78

Improved understanding of these large storm systems should provide the basis for climate prediction and weather modification and for determining the effects of rain, ice, snow, and clouds on communication systems and on the performance of airborne- and satellite-borne weapon systems.

In our research we have emphasized the microscale although the macro- and mesoscales cannot be avoided. The observational equipment and techniques developed for the ABRES programs proved to be excellent tools allowing us to investigate the detailed microphysics associated with cloud and precipitation systems. This type of information is a prerequisite for the construction and testing of the microphysical assumptions used in mesoscale weather prediction models.

The new observations and descriptions of microphysical processes derived from research under this task are being used to improve current mesoscale models in search of more accurate forecasting techniques. Limits on the maximum size of snowflake aggregates (Berthel, 1980[20]) and the change in size distribution with the onset of collisional breakup (Lo and Passarelli, 1981[9]) are already being introduced into cloud physics models.

Eventually, a major, federally funded and controlled program to coordinate the research being conducted at the global, macro-, meso-, and microscale will be needed. This program should unite various segmented research efforts to construct unified, comprehensive models (or series of interdependent models) that will provide improvements in detailed weather forecasts out to a couple of days. Hopefully the knowledge so gained will also improve longer range forecasts.

10.2 Multi-Doppler Radar

As a further aid in measuring the horizontal motion and vertical development of LSCS, plans were made for using the area in which the MIT and AFGL Doppler radars overlapped. A flight program was designed to take airborne data in conjunction with the dual Doppler radar data. The purpose of the joint program was to measure the dynamic and microphysical changes simultaneously. Due to transfer of the MC-130E to a different command, this program was never realized.

10.3 Man-Computer Interactive Data Access System (McIDAS)

The AFGL McIDAS was an integral part of the flying program under this task. McIDAS consists of a geosynchronous satellite ground station, a Harris 6024/5

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20. Berthel, R.O. (1980) A Method to Predict the Parameters of Full Spectral Distribution from Instrumentally Truncated Data, AFGL-TR-80-0001, AD A085950.

microcomputer, and two video terminals. It provides a facility for real-time ingestion and display of GOES imagery and for decoding and archiving surface and upper air data reports transmitted over FAA data line GD 604. Automated plotting and analysis of these data can be performed with the McIDAS graphics capability. Electronic cursors controlled by joysticks at each terminal allow interactive data retrieval and graphics modification.

The McIDAS was used to help guide the sampling aircraft to regions where useful data might be obtained. The McIDAS became an indispensable part of the LSCS flight program and was invaluable in directing the aircraft into storms and showing when the storms were no longer worth sampling.

Future testing of forecast models should expand on the available satellite remote sensing capabilities to measure and predict cloud microphysical parameters such as crystal habit, LWC, and particle size distributions.

10.4 Air Force Applications

A successful hydrometeor characterization of LSCS will benefit the Air Force in several ways. One of the most important benefits is the definition of the hydrometeor hazard to test reentry vehicles for ablation studies and design criteria. Since reentry vehicles are so important in the "Space Age," both as weapons and as scientific instruments, this application really needs no further explanation.

Another potential application is the definition of the hydrometeor environment for high-energy laser transmission. The laser has unlimited potential both as a weapons system and a communications system. A complete knowledge of the environment through which the laser beam passes and its effect is essential.

Yet another application is the contribution of the results of this task to the forming of advanced numerical weather prediction models. Obviously, any insight that can make weather prediction more accurate will benefit all aerospace vehicles and operations. Such potential problems as icing, hazardous weather conditions, and other unusual weather phenomena may be successfully predicted and avoided.

11. CONCLUSIONS

Data obtained under Task 2310G5 have been used to verify a snow growth model, prove the existence of subvisible cirrus, assist the University of Washington in its CYCLES program, and study cirrus cloud systems for advanced weapon systems. A list of all of the in-house and contractor publications under this task makes up Appendix B of this report.

In addition to the above, the development of special instrumentation for this task has led to the Cloud Physics Branch's participation in the U.S. Army's Cold Region Research and Engineering Laboratory's (CRREL) field experiment in Vermont (Berthel, 1982[21]) and also to participation in the launch of the third Space Shuttle flight. Our instrumentation has proven extremely useful in those programs.

Further field programs are still needed. With the change of the scientific direction of the Cloud Physics Branch to modeling, it appears that new flights taken in conjunction with the MIT/AFGL dual Doppler radar system would be extremely useful in model development. Also, a study of the melting layer has pointed out the need for data taken as an airplane flies through that layer. Although Work Unit 2310G501 is now complete, it has paved the way and provided the information needed for further research into large-scale cloud phenomena.

21. Berthel, R.O. (1982) Snow Characterization Measurements at SNOW-ONE-A, SNOW-ONE-A Data Report, (ed., George W. Aitken), Special Report 82-8, May 1982, 421-437, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory.

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13. Cohen, I.D., and Barnes, A.A. (1980) Cirrus Particle Distribution Study, Part 6, AFGL-TR-80-0261, AD A096772.

14. Varley, D.J., Cohen, I.D., and Barnes, A.A. (1980) Cirrus Particle Distribution Study, Part 7, AFGL-TR-80-0324, AD A100269.

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18. Barnes, A.A. (1980b) Observations of ice particles in clear air, Journal de Recherches Atmospherique 14(No. 3-4):311-315; AFGL-TR-81-0347, AD A108914.

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Appendix A

Abbreviations

ABRES	Advanced Ballistic ReEntry System
ADAPT	AVCO Data Analysis and Prediction Techniques
AF	Air Force
AFB	Air Force Base
AFCRL	Air Force Cambridge Research Laboratories
AFGL	Air Force Geophysics Laboratory
AFOSR	Air Force Office of Scientific Research
AFWL	Air Force Weapons Laboratory
ALL	Airborne Laser Laboratory
ASA	Atmospheric Science Associates
ASD	Advecting Spiral Descent
CRREL	Cold Region Research and Engineering Laboratory
CRT	Cathode Ray Tube
CYCLES	Cyclonic Extratropical Storms
DPSI	Digital Programming Services Inc.
DRI	Desert Research Institute
EWER	Evaporate the Water that aggravates Erosion on Reentry
FAA	Federal Aviation Administration
GOES	Geostationary Operational Environmental Satellite
ICBM	InterContinental Ballistic Missile
INS	Inertial Navigation System

KMR	**Kwajalein Missile Range**
LSCS	**Large Scale Cloud Systems**
LWC	**Liquid Water Content**
McIDAS	**Man-Computer Interactive Data Access System**
MIT	**Massachusetts Institute of Technology**
MRI	**Meteorological Research Inc.**
NASA	**National Aeronautics and Space Administration**
NCAR	**National Center for Atmospheric Research**
PMS	**Partical Measuring Systems Inc.**
SASC	**Systems and Applied Science Corporation**
SESAME	**Severe Environmental Storms and Mesoscale Experiment**
TPQ-11	**A vertically pointing, 8 mm wavelength, cloud radar system**
TWCI	**Total Water Content Instrument**
Z	**Radar reflectivity**
1-D	**One Dimensional PMS Probe**
2-D	**Two Dimensional PMS Probe**

Airport 3 Letter Identifications Use in This Report

ABQ	Kirtland AFB, N. Mex. (Albuquerque, N. Mex.)
AMA	Amarillo, Tex.
BED	Hanscom AFB, Mass. (Bedford, Mass.)
BLV	Scott AFB, Ill. (Belleville, Ill.)
BOS	Boston, Mass.
DHT	Dalhart, Tex.
DOV	Dover AFB, Del.
DYS	Dyess AFB, Tex. (Abilene, Tex.)
EDW	Edwards AFB, Calif. (Rosamond, Calif.)
FFO	Wright Patterson AFB, Ohio (Fairborn, Ohio)
FMN	Farmington, N. Mex.
HQM	Hoquium, Wash.
LRF	Little Rock AFB, Ark., (Jacksonville, Ark.)
MCC	McClellan AFB, Calif. (Sacramento, Calif.)
MEM	Memphis, Tenn.
OFF	Offutt AFB, Nebr. (Omaha, Nebr.)
OLM	Olympia, Wash.
PUB	Pueblo, Colo.
TCM	McChord AFB, Wash. (Tacoma, Wash.)
VPS	Eglin AFB, Fla. (Valparaiso, Fla.)
WAL	Wallops Island, Va.

List of Acronyms & Abbreviations for Tables 2 & 3

ADM	Ardmore, Okla.
ALB	Albany, N. Y.
ART	Advanced Radiation Technology program
ASSP	Axial Scattering Spectrometer Probe
CEF	Westover AFB, Mass. (Chicopee, Mass.)
ENE	Kennebunk, Me.
FNL	Shawnee, Okla.
FSSP	Forward Scattering Spectrometer Probe
GAG	Gage, Okla.
GRB	Green Bay, Wis.
HBR	Hobart, Okla.
HYA	Hyannis, Mass.
ICT	Wichita, Kans.
LAW	Lawton, Okla.
MSV	Materials Screening Vehicle program
OKC	Oklahoma City, Okla.
PBG	Plattsburgh AFB, N. Y.
PIA	Peoria, Ill.
PIT	Pittsburgh, Pa.
PSM	Pease AFB, N. H. (Portsmouth, N. H.)
PWM	Portland, Me.
SNS	Salina, Kans.
STJ	St. Joseph, Mo.
TUL	Tulsa, Okla.
TYS	Knoxville, Tenn.
WDG	Woodward, Okla.

Appendix B

Task Reports

B1. IN-HOUSE REPORTS

Barnes, A.A., Jr. (1978) New Cloud Physics Instrumentation Requirements, Preprints, 4th Symposium on Meteorological Observations and Instrumentation, Denver, 10-14 Apr 1978. Published by the Amer. Meteorological Soc., Boston, pp 264-268; AFGL-TR-78-0093, AD A053235.

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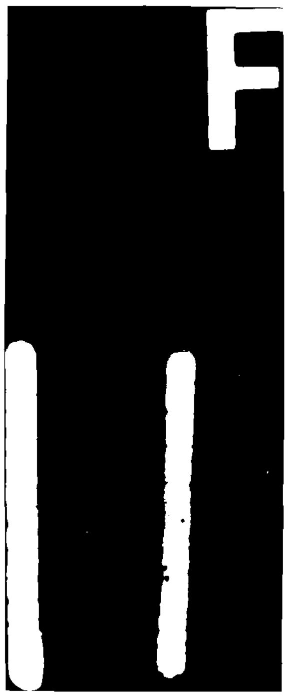
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